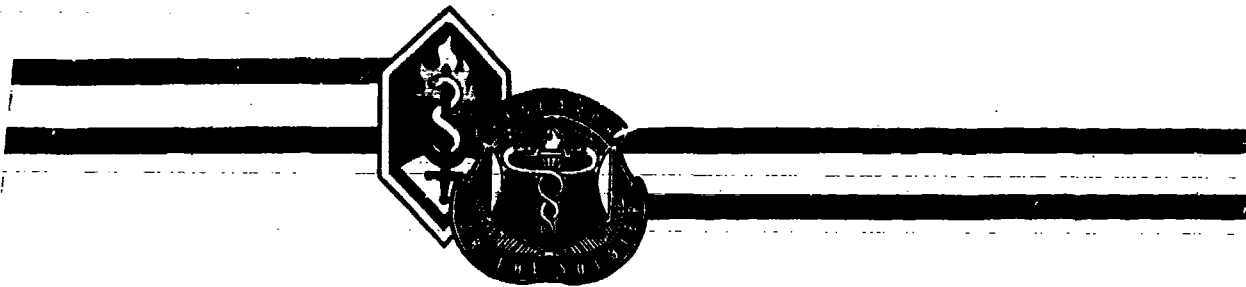


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Evaluation of Speech Intelligibility Through a Bone-Conduction Stimulator

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By

Ted L. Langford
Ben T. Mozo
James H. Patterson, Jr.

Sensory Research Division

July 1989

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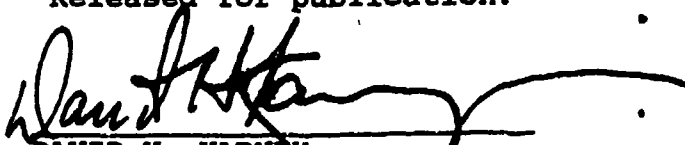


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Introduction

The high noise levels encountered inside many military vehicles require the use of hearing protective devices by crew members. While these devices offer protection against hearing loss, some types, such as earplugs, degrade the intelligibility of speech delivered via conventional voice communication channels. In performing the task of noise attenuation, the earplugs also attenuate the speech signals. The speech-to-noise ratio thus remains the same as in the case in which no plugs are worn. In quiet conditions, the attenuation of the signal produces a net loss in intelligibility.

The present study was designed to test a concept by which the proper use of an earplug would not only protect the crew members from noise-induced hearing loss, but would improve voice communications in the noisy environment of the vehicle.

The occlusion effect is a phenomenon by which the loudness of a bone-conducted sound is enhanced if the ear canal is occluded (Von Bekesy, 1960; Tonndorf, 1972). The effect is greatest at low frequencies, reaching 10 to 18 dB for frequencies below about 2000 Hz, providing the occluding material is inserted tightly and deeply into the canal.

Although the occlusion effect has been studied extensively, no data have been reported for cases in which the signal consisted of speech or for conditions in which a masking noise was present. Since about half of the information in a speech signal lies within the frequency region of the effect, it would appear that occlusion might be employed in the design of a voice communication system for use in high-noise environments. A speech signal delivered in such an environment by bone conduction while the ear canals are occluded by earplugs should be more intelligible than one delivered either by air conduction or by bone conduction with unoccluded or poorly occluded ear canals. The plugs would function both to attenuate the noise and to produce enhanced loudness of the bone-conducted signal.

Methods

Six conditions were run in the experiment. In half of these conditions, the signal was delivered via the conventional, airborne system and in the other half, via the bone-conduction vibrator. For each type of signal delivery, intelligibility was measured either in the quiet or in the presence of a simulated

armored-vehicle noise. In the quiet conditions, the ear canals were open and in the noise conditions were either open or were occluded by triple-flange earplugs fitted by the experimenter.

Twelve subjects, 10 males and 2 females, selected from the subject pool of a local community college, were used in the experiment. Each subject was screened for acceptable hearing on the basis of a pure-tone audiogram obtained for each ear. Acceptable hearing was defined as thresholds between -10 dB and 20 dB at standard audiometric frequencies (ANSI S12.6, 1984). No other selection criteria were employed.

A brief training session preceded the data collection. During this session, each subject was provided with an alphabetized list of the 200 phonetically balanced (PB) words from which the experimental lists were drawn. Adequate time was allowed for the subject to read the list and become familiar with the words and their spellings. Words with alternative, acceptable spellings and words with similar sounds, but which were not interchangeable for test purposes were pointed out by the experimenter, who then read the entire list aloud to familiarize the subject with the sounds of the words. The procedure for data collection was explained and questions asked by the subjects were answered. A practice session during which a PB list was presented at a comfortable listening level via a loudspeaker allowed the subject to become familiar with the temporal pacing of the task and with the printed form upon which the responses were recorded. Data collection began immediately after the familiarization session.

The subjects were seated in a double-walled Tracoustics^{*} audiometric testing booth. The interior dimensions of the booth were 3.05 m x 2.85 m x 1.98 m. The subject sat facing the noise source, an Altec^{*} 604 speaker mounted in a 612C enclosure. The subject's head was 1.63 m in front of the speaker.

The sound field for the noise was calibrated by positioning a 0.5-in microphone at the point in the booth to be occupied by the subject's head. The graphical readout of a GenRad^{*} Real-Time spectrum analyzer connected to the output of the microphone amplifier provided feedback to adjust a one-third octave band filter in the noise circuit to shape the noise field to approximate the frequency spectrum produced by the Bradley Fighting Vehicle. The overall level of the noise was limited to 75 dBA and was checked daily prior to data collection.

* See manufacturer's list.

A Radioear B-71 vibrator mounted in a standard DH-132 helmet was used as the bone-conduction transducer. The vibrator was mounted in a helmet cushion which held it in contact with the right temporal bone in an area above and slightly anterior to the top edge of the helmet's circumaural headphone cushion. This placement did not compromise the acoustic seal of the headphone cushion, which attenuated the airborne radiation from the vibrator.

The helmet mounting ensured the vibrator was always properly positioned when the helmet was donned by the subject. The frequency response of the vibrator was measured on a Bruel and Kjaer Artificial Mastoid with a constant 550-gm pressure and is shown in Figure 1. The frequency response could not be measured under the actual testing conditions and may have varied from subject to subject due to individual differences in head size or amount of hair between the head and the vibrator.

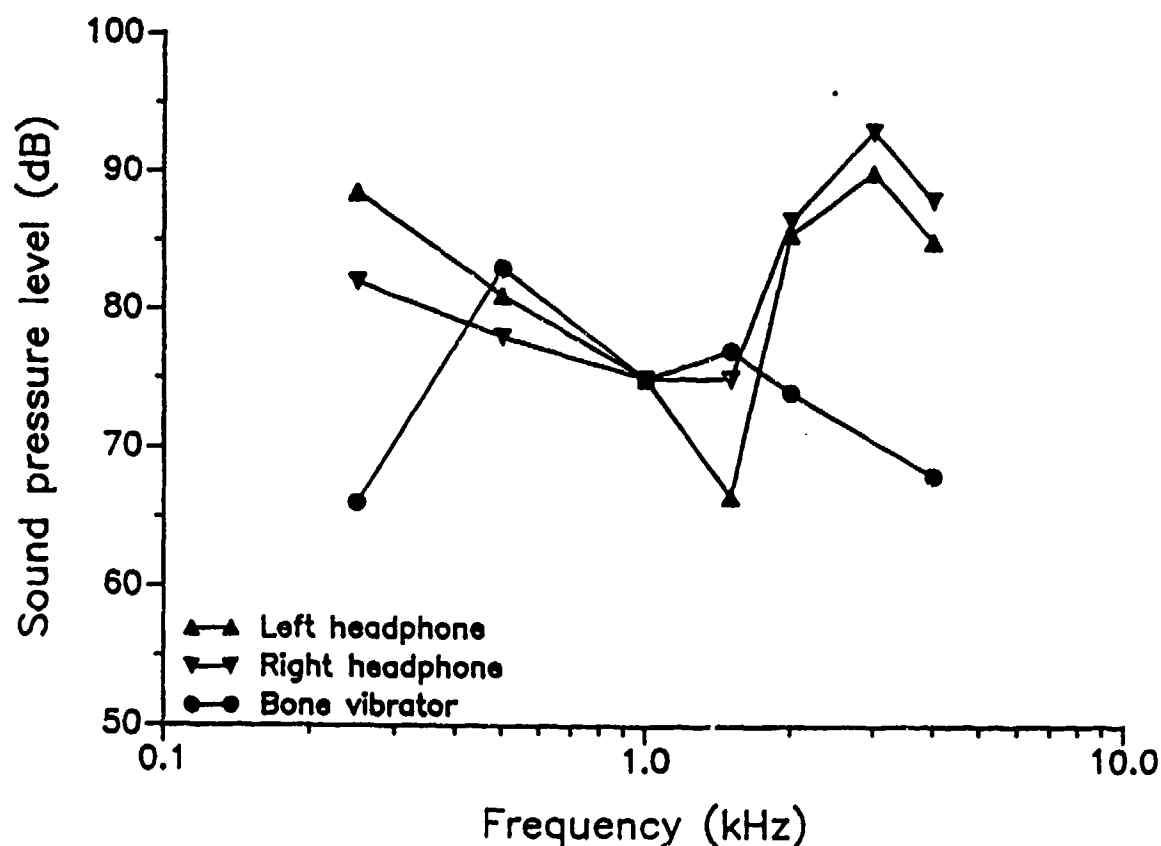


Figure 1. Frequency responses of DH-132 headphones and B-71 vibrator. Ordinate is in sound pressure level for a constant input voltage across headphones. Bone vibrator response is normalized to headphone response at 1000 Hz.

The standard helmet headphones were used as the air-conduction transducers. The frequency response of each of the headphones was measured using a flat-plate coupler and a Bruel and Kjaer 0.5-in microphone. These responses are included in Figure 1. The frequency responses of the two headphones were the same at 1000 Hz, but differed from one another in the low and mid frequencies. The output of the vibrator was normalized to that of the headphones at 1000 Hz, to facilitate the comparison of the two types of transducer. The response of the bone vibrator is quite different from that of either headphone.

Each subject was run for a 1-hour experimental session per day. Usually, two sessions were sufficient to complete all of the conditions. Immediately prior to the presentation of the PB lists for each experimental condition, a speech reception threshold (SRT) was obtained. This provided a quick estimate of the signal levels which would place performance on the PB lists on the straight-line portion of the psychometric function relating signal level and performance. The addition of six dB to the SRT placed performance at approximately 30 percent correct and the addition of 15 dB produced approximately 70 percent correct. Sixteen prerecorded PB lists (Auditek) consisting of four forms each of four 50-word lists were used. Since two levels were used for each of the six conditions, a subject did not hear any given form more than once. The order in which the forms were presented was counterbalanced across subjects and experimental conditions, so that each form followed each of the others with approximately equal frequency. In addition, the order in which the experimental conditions were run was counterbalanced across subjects to compensate for practice effects.

For the SRT determination, the subject responded verbally using a hand-held microphone while the experimenter, in an outer control room, adjusted an attenuator to produce a 50 percent level of performance. When that level was reached, the subject was signaled that a PB list would follow. The responses to the PB lists were made on a printed form. Two lists were presented, one at a level 15 dB greater than the SRT and the other, at a level 6 dB greater. A short break was given during which the experimenter scored the answer sheets and instructed the subject as to the nature of the next condition to be run.

Results

Due to the differences in the frequency responses of the two types of signal-delivery systems used in this experiment, their output levels could not be equated in any meaningful physical units for complex signals such as speech. Therefore, all levels were referred to those

which produced the same performance for each transducer when measured in the quiet, unoccluded condition. The 50 percent level of performance obtained from the psychometric function for that condition was designated as zero dB for both transducers and all other measurements were normalized to that baseline.

The mean psychometric functions for all subjects are shown in Figure 2. The slopes of these functions range from 3.7 percent per dB to 5.5 percent per dB with a mean of 4.5 percent per dB. These are somewhat steeper than the 3.5 percent per dB reported in the classic literature for PB lists (Davis, 1948). The steeper slopes found in the present experiment probably result from the brevity of the training period given the subjects. Performance on PB lists may not reach asymptotic levels until several thousand trials of practice distributed over several days have elapsed (Egan, 1948). Subjects who are less familiar with the stimulus materials, such as those in the

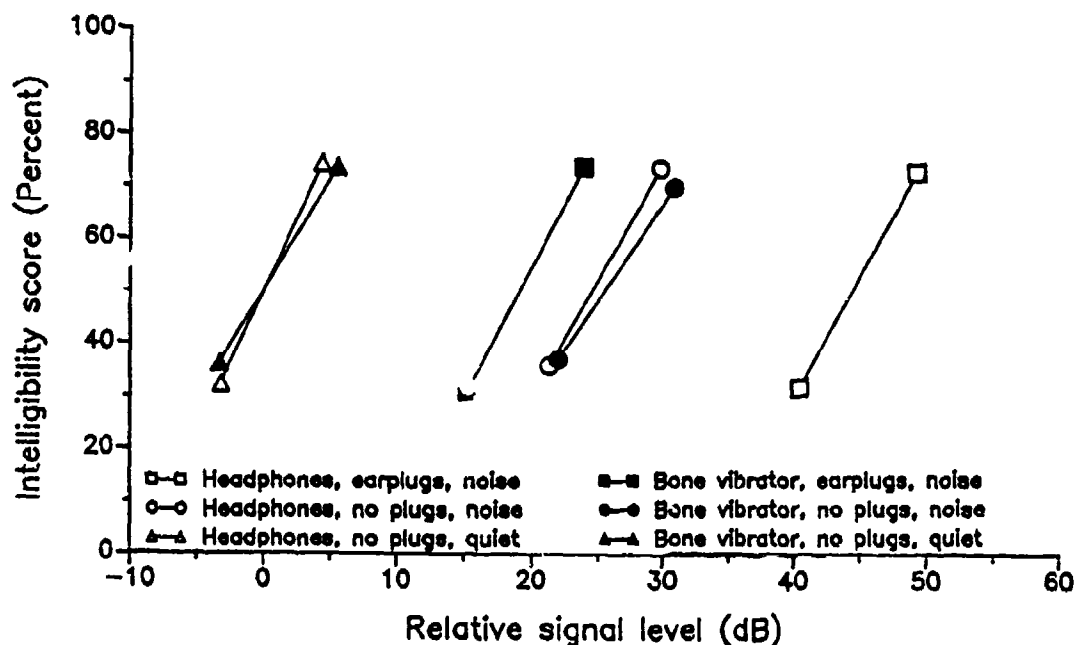


Figure 2. Psychometric functions for intelligibility. All functions normalized to 50 percent score for headphone, no plugs, quiet condition. Data points represent means for all subjects.

present experiment, tend to perform relatively less well at lower signal-to-noise ratios, thus producing a steeper psychometric function. While some practice effects across conditions might be expected in the present experiment, it is felt these were minimized by counterbalancing the order in which the conditions were run by each subject and by averaging across subjects.

Table 1 shows the relative number of decibels required to reach the 50 percent level of performance for each of the conditions. These values were obtained from the mean psychometric functions for all subjects. The data were normalized to the conditions without the noise, so that performance is best, and equal, for these conditions. Only one dB difference is seen between performance with the two transducers in the conditions when the noise was present and no earplugs were worn. This indicates the masking effect of the noise on speech was virtually the same for both the airborne and the bone-conducted signals.

Table 1.

Relative number of decibels for 50 percent intelligibility.
Values are mean for all subjects.

		Quiet	Noise	
		Canals open	Canals open	Canals occluded
Air		0	24.5	44.4
Bone		0	25.5	19.1

The two conditions of greatest interest are those in which the two types of signal-delivery system were compared in the situation common in a military vehicle, that is, in the presence of noise while the listener is wearing earplugs. The normal airborne signal-delivery system used in this situation produced the worst intelligibility for any condition in the experiment. The earplugs offer hearing protection in this condition by attenuating the noise, but at the same time attenuate the signal. The use of the bone-conduction system with the earplugs allowed the same amount of hearing protection and noise

attenuation without any attenuation of the signal. The improvement over the conventional system was 25.3 dB.

The improvement due to the use of the bone vibrator was the result of both the occlusion effect and an improvement in the signal-to-noise ratio. The separate effects of these two variables could not be assessed in the present study. The contribution of the occlusion effect could not be assessed in isolation since the headphone cushion produces some amount of occlusion which is common to all conditions. In addition, the effect of the improved occlusion produced by the earplugs was confounded by the amount of attenuation of the masking noise which they afford.

Conclusions

The use of a bone-conduction signal-delivery system leads to a 25.3-dB improvement in performance in speech intelligibility over the conventional air-delivery system now in use. This improvement is due both to an improvement in signal-to-noise ratio and to the occlusion effect.

Further improvement could result from using headphone cushions which would allow a placement of the bone vibrator in a more sensitive location such as the mastoid and by the use of a bone vibrator with an improved frequency response.

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- Von Békésy, G. 1960. Experiments in hearing. New York: McGraw-Hill. 127-203.

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402 Pasadena Avenue
St. Louis, MO 92803

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GenRad
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